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The Influence of Load Carrying Methods on Gait of Healthy Women

Dr. Wen Ling[1], Dr. Kenneth Axen[2], and Dr. Vern Houston[3]

[1] Associate Professor and Chair
Department of Physical Therapy
New York University
380 2nd Avenue, 4th Floor
New York, NY 10010, U.S.A.
Email: wkl1@is2.nyu.edu

[2] Department of Rehabilitation Medicine
New York University School of Medicine

[3] Department of Rehabilitation Engineering Research
New York Harbor Health System
U. S. Department of Veterans Administration

Summary

Various load configurations on healthy men, but not women, have been examined. Women were found to have higher incidence of musculoskeletal injuries when carrying a heavy load during basic training. The purpose of this study was to examine the changes in gait patterns of healthy women while carrying a 10 Kg. load on the back, around the waist, and across one shoulder. The investigators further evaluated the influence of shoulder muscle strength on their gait with three load carrying configurations. Nine healthy women without existing orthopedic problems in the spine and legs were recruited for this study, ranging in ages from 22 to 32 years, with a mean of 25.2. Their height ranged from 148 to 179 centimeters, with a mean of 161.8. Their weight ranged from 45 to 74.1 kilograms, with a mean of 57.7. Fourteen reflective markers were placed on the subjects' trunk and legs. Two videocameras were used to film the subject walking along a 10 meter walkway. Each subject was first required to walk at her self-selected speed without any load to establish a baseline and then, in random order, walk with a 10-Kg. load on the back, around the waist, and diagonally across one shoulder. The videotape was analyzed using the Ariel Performance Analysis System. Angles of trunk, shoulder, hip, knee, and ankle were calculated. Torque output of subject's shoulder flexors, extensors, abductors, adductors, horizontal abductors, and horizontal adductors were measured on a Biodex II isokinetic dynamometer. Each subject was required to complete three sets of concentric contraction at 150 degrees/second. The total work for three contractions was normalized to each subject's weight. Analyses of variance with repeated measures were used to examine the influence of load carrying methods on gait. Multiple regression analyses were conducted to evaluate the influence of shoulder girdle muscle strength. Results: Subjects walked with significantly different trunk and shoulder angles ($p<0.001$) when walking with three load carrying configurations compared with the baseline and demonstrated the most rigid and flexed trunk when carrying the load on the back. Shoulder angles were significantly asymmetrical when carrying a load diagonally across one shoulder. There was no significant difference in hip, knee, and ankle angles. Shoulder girdle muscle strength strongly correlated with trunk and shoulder angles when carrying a load around the waist or on the back ($r^2=0.855$ to 0.989). Carrying a heavy load around the waist appeared to cause the least deviation from normal gait pattern for women. Women with strong shoulder muscles demonstrated less trunk and shoulder deviations when walking with a heavy load on the back.

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Introduction

Women in the military services were found to have a higher incidence of musculoskeletal injuries when carrying a heavy load during basic training (Ross & Woodward, 1994). Compared with males, females were of smaller stature, and had a wider pelvis, less upper body strength, and smaller feet and ankles. A variety of factors contributed to the high rate of musculoskeletal injuries among military women. Appropriate leg and trunk muscle strength appeared to be critical for women to function on jobs that required carrying loads and walking. Female military trainees with limited leg extensor muscle strength appeared to have a higher incidence of musculoskeletal injuries than female trainees with strong leg extensor muscle (Kowal, 1980). Reinker and Ozburne (1979) reported that poor design of female boots contributed to female trainees' high rate of musculoskeletal injuries during basic training. Various load configurations for healthy men, but not women, have been examined.

The purposes of this study was to examine the changes in gait patterns, heart rates, perceived rates of exertion, and discomfort of healthy women while carrying a 10 Kg. load on the back (using a backpack), around the waist, and diagonally across one shoulder. The researchers further evaluated the influence of should girdle muscle strength on their gait with three load carrying configurations.

Methods

Nine healthy, physically active women without existing musculoskeletal problems in the spine and legs were recruited for this study. Six subjects were physical therapists, one was a massage therapist, and two were full-time college students involved in exercise programs on a regular basis. Their ages ranged from 22 to 32 years, with a mean of 25.2 years. Their height ranged from 148 to 179 centimeters, with a mean of 161.8 centimeters. Their weight ranged from 45 to 74.1 kilograms, with a mean of 57.7 kilograms. The researchers obtained written consent and then conducted a screening examination to ensure each subject was free of musculoskeletal problems in the spine and legs. Fourteen reflective markers were placed on each subject's head, trunk and legs. The markers were placed on the forehead and chin, and then bilaterally on the acromion processes, lateral sides of lower rib cage, greater trochanters, lateral femoral epicondyles, lateral malleoli, and lateral sides of the head of the fifth metartarsal bone. Two industrial level video cameras (Panasonic S-VHS AG-450, Secaucas, NJ 07094) were used to film the subject walking along a 10-meter walkway. One video camera was positioned in the frontal plane facing the walkway. The other video camera was positioned in the sagittal plane at a 60-degree angle to the walkway. Each subject first walked along the 10-meter walkway at her self-selected speed without any load to establish a baseline and then, in random order, walked along the walkway with a 10-kilogram load on the back, around the waist, and diagonally across one shoulder. The videotaped data were processed and analyzed using the Ariel Performance Analysis System (APAS) (Trabuco Canyon, CA 92679) at the sampling rate of 60 Hertz. The APAS calculated three-dimensional joint angles of the trunk, shoulder, hip, knee, and ankle.

Subjects then walked for one hour on a treadmill (Quinton 50) at 3.3 miles/hour with no load on the first day. Subjects then walked for one hour on the treadmill at 3.3 miles with the load using one of the three load configurations, assigned in a random order, on three consecutive days. Inclination of the treadmill was changed randomly every ten minutes, ranging from one to seven percent. Each subject followed the same treadmill protocol for the four testing conditions. While subjects were on the treadmill, the researchers monitored the heart rate, perceived rate of exertion, and discomfort every ten minutes. Heart rate (beats/minute) was monitored continuously using an ECG telemetry system (Physiodyne Instruments, Farmingdale, NY 11735). The modified Borg scale, ranging from one to ten, measured the perceived rate of exertion. A Visual Analog Scale, ranging from 0 (no paint) to 100 millimeters (the most intense pain), was used to measure the level of discomfort. Four testing conditions were conducted on four different days for each subject.

In the fifth session, each subject's shoulder girdle muscle strength was measured by the Biodex II isokinetic dynamometer (Biodex Medical, Shirley, NY, 11967). The researchers followed the standard testing positions as recommended by the Biodex manufacturer to test each subject's shoulder flexors, extensors, abductors,

adductors, horizontal abductors, and horizontal adductors bilaterally. After the warm-up routine, each subject completed three sets of contractions in the concentric mode, at 150 degrees/second, for each muscle group tested. The total work for three contractions was normalized to each subject's body weight to be used for data analysis.

The researchers used the Statistical Package for Social Science for Windows (version 10.0) to conduct statistical analysis. Analyses of variance with repeated measures were used to examine the influence of load carrying configurations on joint angles, heart rate, perceived rate of exertion, and discomfort. Multiple regression analyses were conducted to evaluate the influence of shoulder girdle muscle strength on gait.

Results

The researchers examined the trunk angle from the sagittal plane using the APAS to calculate the angle between the trunk markers and the horizontal line. A smaller trunk angle indicated more forward flexion of the trunk. Trunk angles were examined at heel strike, foot flat, midstance, heel off, and toe off points of the stance phase. See Table 1 for the mean trunk angles for the baseline and the three load-carrying conditions. Subjects showed most trunk forward flexion when carrying the load on the back. When subjects carried the load around the waist, their trunk angles were similar to those of the baseline condition. Trunk excursion angle was calculated as the absolute difference of trunk angle between heel strike and toe off. Trunk excursion angles varied significantly between the baseline measurement and three load-carrying configurations ($p<0.001$). Subjects showed the least amount of trunk excursion when carrying the load on the back (see Table 2).

Table 1. Mean Trunk Angles (degrees) during the Stance Phase of the Gait Cycle

	Baseline	Backpack	Waist*	Shoulder**
Stance Phase				
Heel Strike	103.53	89.13	100.79	98.51
Foot Flat	103.94	90.37	102.93	99.93
Midstance	97.76	86.72	94.4	95.04
Heel Off	94.09	84.17	91.31	92.68
Toe Off	95.75	87.66	91.31	96.17

*Waist – Carrying the load around the waist
**Shoulder – Carrying the load across one shoulder

Table 2. Mean Trunk Excursion Angles (degrees) during the Stance Phase of the Gait Cycle

	Trunk Excursion Angle (Degrees)*
Baseline	7.79
Backpack	1.48
Around the Waist	9.48
Across One Shoulder	2.34

* $p<0.001$

The researchers examined the shoulder angle from the frontal plane. The APAS used 180 degrees to represent the horizontal line. Numbers smaller or bigger than 180 indicated shoulder asymmetry. Shoulder angles were examined at heel strike, foot flat, midstance, heel off, and toe off points of the stance phase. Subjects showed the most shoulder asymmetry when carrying the load across one shoulder (see Table 3). The shoulder excursion angle was calculated as the absolute difference between the shoulder angle at heel strike and toe off. Subjects showed significant differences in shoulder angle between the baseline measurement and the three load carrying configurations ($p<0.0009$). They showed the least amount of

excursion when carrying the load across one shoulder. Subjects showed similar shoulder excursion angles during the baseline condition and when carrying the load around the waist (see Table 4).

Table 3. Mean Shoulder Angles (degrees) during the Stance Phase of the Gait Cycle

	Baseline	Backpack	Waist*	Shoulder**
Stance Phase				
Heel Strike	177.88	179.1	177.16	176.92
Foot Flat	178.1	179.16	176.75	176.19
Midstance	180.09	180.62	178.88	176.89
Heel Off	181.07	180.95	180.37	177.34
Toe Off	181.66	181.32	181.05	177.17

*Waist – Carrying the load around the waist
**Shoulder – Carrying the load across one shoulder

Table 4. Mean Shoulder Excursion Angles (degrees) during the Stance Phase of the Gait Cycle

	Shoulder Excursion Angle (degrees)*
Baseline	3.78
Backpack	2.22
Around the Waist	3.89
Across One Shoulder	0.25

* $p < 0.0009$

Hip, knee, and ankle angles were similar during the baseline and the three load-carrying conditions. Subjects did not show significant differences in maximal heart rate. The mean maximal heart rate ranged from 130 beats/minute when carrying the load across one shoulder to 137 beats/minute when carrying the load on the back. Subjects did not showed any significant differences in the perceived rate of exertion. The perceived rate of exertion was the lowest when carrying the load around the waist (4.3 +/- 0.4) and the highest when carrying the load across one shoulder (5.9 +/- 0.9). Subjects did not show significant differences in the level of discomfort reported. The researchers found the discomfort reported by the subjects was the lowest (5 +/- 1 mm) when they carried the load around the waist and the highest (64 +/- 9 mm) when they carried the load across one shoulder. Subjects reported high levels of discomfort generally towards the end of the treadmill session.

The researchers conducted the multiple regression analysis in three steps to examine the influence of each shoulder muscle group on trunk and shoulder angle deviations at heel strike. Trunk angle deviation was the absolute difference between trunk angle during the baseline condition and during each load carrying condition. Shoulder angle deviation was calculated in a similar manner. The researchers first entered the horizontal abductors and horizontal adductors, then the abductors and the adductors, and lastly the shoulder flexors and extensors into the multiple regression formula. The researchers found that at heel strike, six shoulder muscle groups strongly predicted the trunk angle when subjects were carrying the load around the waist ($r^2 = 0.941$). Shoulder girdle muscle strength also positively correlated with trunk angle when subjects were carrying the load across one shoulder ($r^2 = 0.72$) and on the back ($r^2 = 0.65$) (see Table 5). The researchers found that at heel stroke, six shoulder muscle groups strongly correlated with the shoulder angle deviations when subjects carried the load on the back ($r^2 = 0.697$) and around the waist ($r^2 = 0.621$) (see Table 6).

Table 5. Multiple Regression Analyses (r^2) of Shoulder Girdle Muscle Strength and Trunk Angle Deviations at Heel Strike

	Backpack	Waist	Shoulder
Step 1	0.085	0.468	0.284
Step 2	0.11	0.885	0.612
Step 3	0.65	0.941	0.72

Step 1. Horizontal abductors and horizontal adductors
Step 2. Muscles from Step 1, abductors, and adductors
Step 3. Muscles from Step 2, flexors, and extensors

Table 6. Multiple Regression Analyses (r^2) of Shoulder Girdle Muscle Strength and Shoulder Angle Deviations at Heel Strike

	Backpack	Waist	Shoulder
Step 1	0.476	0.272	0.215
Step 2	0.593	0.371	0.263
Step 3	0.697	0.621	0.375

Step 1. Horizontal abductors and horizontal adductors
Step 2. Muscles from Step 1, abductors, and adductors
Step 3. Muscles from Step 2, flexors, and extensors

Discussion

An optimal load-carrying configuration should allow a person to walk with normal reciprocal shoulder, trunk, and leg movements with the least of amount of effort and discomfort. Subjects showed similar hip, knee, and ankle angles when walking with no load and carrying the load in three configurations. Subjects showed changes in trunk and shoulder angles. Carrying the load around the waist appeared to be the optimal load-carrying configuration according to the results of this study. Subjects showed similar trunk and shoulder movements during the baseline (no load) condition and when carrying the load around the waist. Subjects reported low levels of perceived rate of exertion and discomfort while carrying the load around the waist. Carrying the load on the back appeared to make subjects flex the trunk more forward with limited trunk forward/backward movements during ambulation. Our findings are supported by the findings of Harman and his associates (1999). Harman and his associates reported that female soldiers showed more trunk forward flexion when the load carried in a specialized frame increased. The least favorable load-carrying configuration tested in our study was carrying the load across one shoulder. Subjects showed significantly more shoulder asymmetry and significantly less shoulder movements when carrying the load across one shoulder. Subjects reported the highest level of discomfort when carrying the load across one shoulder. Subjects reported discomfort on neck, shoulder, and back when carried the load across one shoulder. They kept moving their shoulders trying to shift the load while walking on the treadmill. The task tested in this study was walking on a treadmill at 3.3 miles/hour with the gradient changing every ten minutes from one to seven percent. The physiological work performed by subjects on the treadmill appeared to be within their physical tolerance as indicated by similar heart rate between the baseline measurement and the three load configurations.

The researchers examined the influence of the shoulder girdle muscles on the deviation of the trunk and shoulder movements when carrying the load from the baseline condition. When carrying the load around the waist, the shoulder horizontal abductors, horizontal adductors, abductors, and adductors strongly influenced subjects' trunk movement deviations. The shoulder girdle muscles (horizontal abductors, horizontal adductors, abductors, adductors, flexors, and extensors) strongly influenced subjects' shoulder movement deviations when carrying the load on the back or around the waist. Apparently, shoulder girdle muscle strength positively correlated with a woman's trunk and shoulder movements while walking with a heavy load around the waist or on the back.

Conclusion

Carrying a heavy load around the waist appeared to be most optimal for women, causing the least deviation from normal gait pattern, least effort, and the lowest level of discomfort. Shoulder girdle muscle strength positively influences shoulder and trunk deviations during ambulation when women carrying a heavy load around the waist or on the back.

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